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NOTES ON
PHYSICAL GEOGRAPHY AND GEOLOGY.

PART IV.
HISTORICAL GEOLOGY.

J. V. Elsden B.Sc., F.C.S. and W. B. Lowe. M.A., F.C.S.

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NOTES ON
PHYSICAL GEOGRAPHY AND GEOLOGY.

Designed for the use of Students preparing for
Competitive Examinations.

BY

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AND

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RUGBY.
A. PERCY SMITH.
1883.

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PREFACE.

Circumstances have led to the appearance of the Notes on Historical Geology before the other parts could be got through the press. Being intended solely as a note book, it was thought advisable to supply blank pages on which any additional matter can be inserted opposite the proper place. The fossils given are few, and give but an incomplete view of the life of each period. This is a necessary defect in a system of notes, intended only to form a skeleton upon which to hang more complete details, according to the capacity of the student.

Some errors still remain in the text, to which attention is primarily directed.

Storrington, Oct. 1883. J. V. E.

ERRATA.

Page	2,	line	5,	*for*	Pleiocene	*read*	Pliocene.
„	4,	„	26,	„	St. Davids's	„	St. David's.
„	6,	„	2,*	„	Luldow	„	Ludlow.
„	9,	„	13,	„	Lepidodrendron	„	Lepidodendron.
„	10,	„	25,	„	whlie	„	while.
„	11,	„	4,*	„	colapsed	„	collapsed.
„	12,	„	8,*	*insert* and roots *before* Stigmaria.			
„	19,	„	19,	*for*	spirosa	*read*	spinosa.
„	„	„	21,	„	cestata	„	costata.
„	21,	„	14,	„	vcry	„	very.
„	„	„	2,*	„	U'	„	U.
„	28,	„	11,	„	Petunculus	„	Pectunculus.
„	30,	„	14,*	„	recesssion	„	recession.

* From bottom.

PART IV.

HISTORICAL GEOLOGY.

Historical or Stratigraphical Geology has for its purpose the interpretation of the past Geological history of the Earth. The following are its chief objects:—

1. To establish the order of superposition of the strata which occur in the earth's crust.

2. To subdivide these strata into natural groups or *formations*, each marked by a general resemblance in their organic remains.

3. To establish the succession of organic types. When traced backwards, existing species of plants and animals give place to other forms, which, in turn, die out and are succeeded by other species. The stratified rocks are thus shown to contain the records of a gradual progression of types of life.

The following is the order of the succession of the stratified formations of the earth's crust.

HISTORICAL GEOLOGY.

QUATERNARY OR POST-TERTIARY.

Recent and Prehistoric.
Pleistocene.

TERTIARY OR CAINOZOIC.

Pleiocene.
Miocene.
Oligocene.
Eocene.

SECONDARY OR MESOZOIC.

Cretaceous.
Jurassic.
Triassic.

PRIMARY OR PALÆOZOIC.

Permian.
Carboniferous.
Devonian and Old Red Sandstone.
Silurian.
Cambrian.

ARCHŒAN OR EOZOIC.

Huronian.
Laurentian.

HISTORICAL GEOLOGY.

ARCHŒAN OR EOZOIC TIME.

Beneath the oldest unaltered fossiliferous formations occur masses of metamorphic rocks to which no definite age can be assigned. In the Hebrides and N. W. Scotland, these rocks are supposed to be equivalent to the Laurentian and Huronian of Canada.

At St. David's, Dr. Hicks has divided them into two groups, a ridge consisting of Dimetian rocks, above which is a middle group of volcanic rocks called Arvonian, flanked unconformably on either side by Pebidian strata. In the Malvern hills they form an axis of syenitic gneiss, and the Wrekin in Shropshire has a similar structure.

The metamorphic rocks of Charnwood forest may possibly belong to the same remote period.

Sir A. Ramsay maintains that the older gneiss, as well as the metamorphosed rocks of Carnarvon and N. W. Anglesey are altered Cambrian rocks.

1. Laurentian Period.

So called from the large development of rocks of this age on the banks of the St. Lawrence.

Divisions. Upper Laurentian, (10,000 ft.) consisting chiefly of Labradorite and Hypersthene.
Lower Laurentian (20,000 ft.), hornblendic gneiss and serpentinous limestone.

Localities. In a V shape from valley of St. Lawrence to Labrador on the E. and Brit. N. America on the W.

Britain — Outer Hebrides and N. W. Scotland.

Europe — Bavaria; Bohemia; Finland; Scandinavia.

Fossils. These rocks were formerly supposed to be unfossiliferous, until the discovery, by Sir W. Logan, of a curious structure believed to represent a huge reef-building Foraminifer, to which the name *Eozoon Canadense* has been given. This fossil is only known to occur in the serpentinous limestones of Canada. Similar structures, found in Bohemia and Bavaria, are now believed to be of mineral origin. The beds of graphite, so abundant in the Laurentian limestones of America, are possibly of organic origin.

The upper Laurentian has hitherto yielded no fossils.

Economic Products. Thick layers of graphite; large beds of iron ore, sometimes 200 ft. thick.

2. Huronian Period.

So called from Lake Huron in Canada. These beds, 10,000 to 20,000 ft. thick, consisting of slates, conglomerates, limestones and quartzites, rest unconformably on the Laurentian rocks, from which they have been partly derived. They contain no fossils.

It is possible that the conglomerates overlying the Laurentian gneiss of Scotland, and usually called Cambrian, are really of Huronian age.

PRIMARY OR PALÆOZOIC TIME.

1. *Cambrian Period.*

Divisions. Upper — 4. Tremadoc slates.
3. Lingula flags.
Lower — 2. Menevian flags.
1. Longmynd series { Llanberis slates.
Harlech grits.

Localities. Wales ; Scotland ; Ireland ; Central Europe and North America.

Longmynd series. Shales and sandstenes of the Longmynd in Shropshire ; the Harlech grits of Merionethshire ; the Penhryn and Llanberis slates in Carnarvon. At St. David's they occur on either side of the Archœan ridge, consisting of conglomerates at the base (hence probably shore deposits), passing up into shales and sandstones with numerous fossils. Similar rocks occur also in Ireland, in the Counties of Wicklow and Dublin.

Fossils.	Protozoa.	Protospongia (St. David's only).	
	Hydrozoa.	Oldhamia radiata & antiqua (Ireland only).	
	Annelida.	Arenicolites.	
	Trilobita.	Palœopyge Ramsayi (Shropshire only).	
		Paradoxides Davidis.	St. David's only.
	Brachiopoda.	Lingulella ferruginea.	
	Pteropoda.	Theca.	

Menevian beds lie unconformably on Harlech grits at St. David's and in Merionethshire.

Fossils. The St. David's fossils of the Longmynd series, given above, occur also in the Menevian.

Lingula flags. Dark flags and slates, divided into three groups :—
Upper or Dolgelly group.
Middle or Festiniog group.
Lower or Maentwrog group (Olenus beds).

They occur in Merionethshire, Carnarvonshire, St. David's and W. of the Longmynd. At Malvern, the middle Lingula flags are represented by the Hollybush sandstone and the upper by the black shales, associated with volcanic rocks.

Fossils.	Polyzoa.	Dictyonema sociale (only in upper beds).
	Trilobita.	Olenus.
	Phyllopoda.	Hymenocaris vermicauda.
	Brachiopoda.	Lingulella Davisii.

Tremadoc slates rest conformably on Lingula flags. They occur at Tremadoc, Dolgelly, St. David's and near the Wrekin.

Fossils. Angelina (Trilobite), Orthoceras first appears.

Volcanic action. Lines of ash beds.

Economic products. Slates. A little gold has been found at the base of the Lingula flags.

Erratum ☞

May Hill group consists of	**Tarannon shale.** **Upper Llandovery.** **Lower Llandovery.**

2. *Silurian period.*

Divisions.		*Wales.*	*Lake district.*
Upper.	Passage beds.	Ledbury shales.	
		Downton sandstones.	
	Ludlow beds.	Upper Ludlow shales.	Kirkby moor flags.
		Aymestry limestone.	
		Lower Ludlow shales.	Bannisdale slates.
	Wenlock group.	Wenlock limestone and shale.	
		Woolhope limestone and shale.	Coniston grits and flags.
		Denbighshire grits.	
	May Hill group.	Tarannon shale.	Stockdale slates.
		Upper Llandovery.	
Lower.		Lower Llandovery.	
		Bala and Caradoc.	Coniston limestone.
		Llandeilo.	Green slates and porphyries, (volcanic series).
		Arenig & Stiper stones.	Skiddaw slates.

Localities. England, Wales, Scotland, Ireland, Europe, North and South America, Asia and Australia.

Lower Silurian.

Arenig group. (Lower Llandeilo, Murchison). These consist of shales, slates and sandstones, and quartzose rocks of Shropshire called Stiper stones. They occur in the Arenig Mts. of Merionethshire, at the Shelve in Shropshire, and St. David's.

Fossils. Graptolites first appear and are strongly developed [Didymograptus]. *Trilobites,* Ogygia Buchii.

An unconformity between these beds and the Tremadoc slates is proved [1] by a palœontological break. Of 150 Arenig species only 16 are common to the Tremadoc beds below, [2] by an extensive overlap ; so that the Arenig, which in the S. rest upon Tremadoc slates and Lingula flags, near Bangor lie directly on rocks of the Longmynd series.

Volcanic action. Piles of lava and ashes were thrown out in this period from Cader Idris, Aran Mawddy, the Arenigs and Moelwyn in Wales, and Helvellyn and Scawfell in the Lake district.

Llandeilo group consist of flags with shales or slates at the base. They occur in Pembrokeshire, Builth (Radnor), Llandeilo (Caermarthen), and the Shelve (Shropshire).

Fossils. Trilobites. Asaphus tyrannus.
Graptolites still abundant.

Caradoc or Bala group consist of grey slates, grits and sandstone, with two beds of limestone, viz., lower or Bala limestone, and upper or

Hirnant limestone. They occur at Caer Caradoc in Shropshire, and round Bala in Merionethshire. Snowdon is built up of lavas and fossiliferous stratified ashes of this age, showing contemporaneous volcanic action.

Fossils.	Crustacea.	Trinucleus concentricus.
	Brachiopoda.	Orthis vespertilio.
	Gasteropoda.	Murchisonia.
	Echinoderm.	Palœaster asperrima.
	Cephalopoda.	Lituites cornu-arietis.

Lower Llandovery beds are conformable to, and at first were included amongst, the Caradoc beds. They are characterised by *Pentamerus* (*Stricklandinia*) *lens*, a Brachiopod. They cover a considerable breadth of Cardigan and Caermarthenshire.

Upper Silurian.

Upper Llandovery group rests unconformably upon the underlying rocks. In their lower parts they consist of conglomerates, hence probably beaches; in their upper parts sandstones. They are characterised by *Pentamerus oblongus* and *Petraia bina* (coral). They occur in Shropshire, Radnor, May Hill, Malvern and Licky hills.

Tarannon shales are pale slates and shales. They rest conformably on the upper Llandovery in S. Wales. In N. Wales they extend from the mouth of the Conway to Builth. No fossils.

Wenlock group. Denbighshire grits are found overlying the Tarannon shales. Woolhope shale and limestone occur at Woolhope near Hereford, Malvern, Wenlock edge and Barr in Staffordshire. Wenlock shale and limestone occur at Usk, May Hill, Ledbury, Malvern, Wenlock edge and Dudley.

Fossils.	Corals.*	Halysites catenularia.
		Favosites Gothlandica.
		Omphyma turbinatum.
	Trilobita.	Phacops caudatus.
		Calymene Blumenbachii.
		Homalonotus delphinocephalus.
	Brachiopoda.	Atrypa reticularis.
		Strophomena depressa. S. euglypha.
		Rhynconella Wilsoni.
		Orthis elegantula.
	Gasteropoda.	Euomphalus.
	Cephalopoda.	Orthoceras annulatum.
	Heteropoda.	Bellerophon Wenlockensis.

* Corals are a distinguishing feature of Wenlock limestone.

Ludlow group. Lower Ludlow shales, Aymestry limestone (characterised by *Pentamerus Knightii*), and Upper Ludlow shales.

They occur through Brecon and Caermarthen, but are typically seen between Luldow and Aymestry. They occur also, in detached areas, from Dudley to the mouth of the Severn.

Fossils.	Asteroidea.	Protaster Miltoni.
	Crustacea.	Pterygotus.

Vertebrata first appear. The earliest known fish is Scaphaspis ludensis (Lower Ludlow). In the Upper Ludlow is a bone bed with Onchus tenuistriatus (Placoid), and Pteraspis (Ganoid).

Downton sandstones and Ledbury shales. These are passage beds occurring between the Ludlow and the Old Red, especially at Ledbury and Malvern. Some of these beds are incorrectly called Tile-stones.

They show the commencement of the gradual disappearance of the Silurian sea with its crowd of *Graptolites*, *Trilobites* and *Brachiopods.*

As soon as the overlying Red strata begin, these species quickly die out, until only the *fish* and large *Eurypterid* crustaceans continue to occur.

Fossils.	Pterygotus.	Eurypterus.
	Brachiopoda.	Lingula.
	Cephalopoda.	Lituites.
	Fishes.	Cephalaspis. Onchus. Pteraspis.

In the Downton sandstones occur traces of land plants (probably *Lycopodiaceous* seeds) the oldest known plant life.

Economic products. The oldest known Salt deposits occur in the Upper Silurian of New York and in the Salt range of the Punjaub. Rich copper mines around Lake Superior. In Britain, lead and copper ore are found as well as a few slates.

NOTE. It is characteristic of older Palœozoic limestones to occur in a very lenticular form, swelling in some places to a great thickness and rapidly thinning out, to re-appear, perhaps some miles away, with increased proportions. This local character is well exhibited by the Woolhope limestone. Where it dies out, the shales beneath join on to the overlying Wenlock shale, and no line of demarcation can then be seen between them.

3. Old Red Sandstone and Devonian periods.

In the W. and N. W. Europe the Silurian sea bed was upraised (as seen by the passage beds just described) so as to enclose large inland basins in which were deposited the freshwater Old Red Sandstone strata, while the sea continued to cover the centre and S. W., in which areas the marine Devonian strata were formed. Thus the Old Red Sandstone and Devonian do not represent different periods of time, but different geographical conditions of the same period.

Proofs of contemporaneity of the Old Red and Devonian.

1. Physical evidence. In the Eifel district, Devonian rocks form a complete link between Silurian and Carboniferous strata, while in Scotland the Old Red strata occupy a similar position.

2. Palœontological evidence. In the Continental Devonian occur some species which are common to the Old Red Sandstone.

3. In Russia the Devonian and Old Red appear to be united into one system. Cases occur in which, in the same band of rock, Devonian shells and Old Red fishes are mingled; while in other cases the marine limestones of the one are interstratified with the fish-bearing sandstones of the other.

Devonian type.

Upper Devonian.	Slates and sandstones of Pilton and Pickwell-Down, Devon.
Middle Devonian.	Slates of Ilfracombe, and limestones of Plymouth and Torbay.
Lower Devonian.	Sandstones and slates of Lynton.

Localities. Devon and Cornwall, whence they probably extend away to the Eifel district (since they were reached beneath London in the boring at Meux's brewery); and N. America.

Fossils.	Crustacea.	Bronteus flabellifer.
	(Trilobites become rarer and more ornamented).	
	Brachiopoda.	Stringocephalus Burtini.
		Spirifera disjuncta.
	Lamellibranchiata.	Megalodon cuculatus.
	Cephalopoda.	Clymenia linearis.
		Goniatites. (first appearance).

Most of the fossils occur in the limestones of the middle Devonian, the other strata being too much metamorphosed.

In central Europe there is evidence of considerable volcanic action during this period.

Possibly the lower Devonian strata may represent the uppermost Silurian of other districts, since, where the lower Devonian are best developed, the upper Silurian can scarcely be recognised. Jukes considered that the Devonian of Devonshire are of Carboniferous age, from the fact that the upper beds resemble the lower Carboniferous of South Ireland. This view is confirmed by the resemblance of the land plants and shells of the upper Devonian to those of the lower Carboniferous limestone shales.

Economic products. Ores of iron, lead, tin, copper etc., occur in veins in the Devonian of Cornwall, Devon, Hartz Mts. etc. The Devonian of Pennsylvania contain bands of sand-rock filled with petroleum.

Old Red Sandstone type.

	Upper Old Red.	Yellow and red sandstones and conglomerates.
Cornstone group.	*Middle* ,, ,,	Marly sandstones and flagstones and thin cornstones (brownstone series). (occurs only in the N. of Scotland).
	Lower ,, ,,	Cornstones and sandstones. (cornstone series).

Localities. S. Wales, Scotland and Ireland.

Fossils.	Crustacea.	(Eurypterida). Pterygotus Anglicus.*
	Lamellibranchiata.	Anodonta Jukesii (first freshwater bivalve).
	Fishes.	Cephalaspis Lyelli. Pterichthys Milleri. Holoptychius nobilissimus. Osteolepis.†

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* Often 6 ft. in length. † Nearest analogues in fresh-water lakes of Canada, and in the Mississippi and African rivers.

Mode of formation of the Old Red strata.

These rocks were probably accumulated in isolated basins. In Scotland there appear to have been four of these inland sheets of water, 1. *Lake Orcadie*, extending from the shores of the Moray Firth to the Orkneys. 2. *Lake Caledonia*, occupying the central valley of Scotland. 3. *Lake of Lorne*, a small basin around Oban. 4. *Lake Cheviot*, extending from Berwick to the Solway Firth. The red colour of the rocks is probably due to the precipitation of oxide of iron from the waters of these lakes. It is noticeable that red rocks are usually barren of organic remains.

Proofs of fresh-water origin of Old Red.

1. Fishes and shells are fresh-water species.
2. Ferns occur, viz., *Adiantites*, *Lepidodendron* and *Calamites* (flora similar to Carboniferous).

The presence of a few brackish or marine species is no argument against the fresh-water origin of these beds, since seals occur in inland fresh-water lakes of Newfoundland and Baikal, and formerly existed in Aral. Marine Crustacea occur also in some of the lakes of Sweden. Owing to slowness of change, marine species would be able to adapt themselves to new conditions: e. g., the shells in the Black sea are strangely distorted through a gradual freshening of the water.

Volcanic action. The Grampians, Ochill, and Pentland hills of Scotland were a series of Old Red volcanoes.

Economic products. Sandstone for building. The soil is very suitable for orchards, and is especially fertile where cornstones appear.

4. *Carboniferous period.*

During the Carboniferous period, the land from which the chief part of the sediment was derived rose towards the N. and N. W., the southern portion being covered by moderately deep water, and the N. of England and S. of Scotland by shallow water. Hence we shall find great differences in the nature of the deposit in different areas.

The following are typical sections in various localities.

S. W. England and S. Wales.	Midland counties.	Lancashire, Yorkshire and Derby.	Northumberland and Durham.	Central valley of Scotland.
Upper coal measures.	**Coal measures.**	**Upper coal measures.**	**Up. C. m. (thin coal).**	**Up. coal series.**
Pennant grit.		**Middle coal measures.**	**Middle ,, (thick).**	
Lower coal measures.		**Lower or Gannister beds.**	**Lower or Gannister [thin].**	
Millstone grit (Farewell rock).	**Millstone grit.**	**Millstone grit, with thin coal.**	**Millstone grit, with thin coals.**	**Moor rock or Millstone grit, with coals & limestone.**
Upper limestone shale.	**Yoredale.**	**Yoredale rocks.**	**Yoredale [carb. limestone], coals, shales, grits & limestones.**	
Carboniferous limestone.		**Carb. limestone.**		
Lower limestone shale.				
			Tuedian beds viz. sandstones & shales with plants, no coal, argillaceous limestone.	**Calciferous sandstone, with occasional coal.**
Old Red Sandstone.	**Silurian.**			

Chief Coal fields of the British Isles.

Locality.	*Coal beds.*	*Locality.*	*Coal beds.*
S. Wales	101.	S. Staffordshire	7.*
Forest of Dean.	23.	N. Staffordshire.	28.
Bristol and Somerset	87.	Notts. Derby & Yorkshire.	19.
Shrewsbury, Coalbrook-dale, Forest of Wyre & Clee hills.	18.	Lancashire & Cheshire...	40.
Warwickshire	5.	N. Wales.	41.
Leicestershire	30.	Northumberland & Durham.	9.
		Cumberland.	12.

* One 40 ft. thick.

Localities. In Devonshire the *Culm measures* consist of altered shales, with impure bands of limestone and a little Millstone grit, but no useful coal. Shown by fossils to be of Lower Carboniferous age. They are much crumpled and metamorphosed, the coal having been thus rendered anthracitic.

In the central valley of Scotland there are five coal fields.

In Ireland several coal fields occur as outliers upon the Carboniferous limestone; those of Connaught, Tyrone and Ballycastle being bituminous, while those of Clare, Cork and Kilkenny are anthracitic. They are of small importance.

Important coal fields are also found on the Continent, especially in Belgium, France, Germany and Bohemia. In N. America there are large coal fields in the Appalachians, Illinois, Missouri, Nova Scotia and New Brunswick. In New South Wales there are important coal seams, whlie, in China, horizontal coal measures, with seams 30 ft. thick, are said to cover an area of 30,000 square miles.

The Carboniferous limestone and Millstone grit usually occur bordering the coal fields. Towards the N. the limestone gradually thins out and gives place to coal-bearing sandstones and shales. In England the Carboniferous limestone is called "Mountain limestone" since it generally forms high ground. As such, it contributes much to the scenery of Derbyshire, Yorkshire, Monmouth, Leicester, Somerset, Gloucester and Wales. The absence of Carboniferous limestone from the Midland counties may be due either to denudation or to non-deposition, possibly from the existence of a ridge of land in that district.

In Ireland, the Carboniferous limestone, with a thickness of about 3,000 ft., forms most of the central plain. In the N., however, the limestone is divided into an Upper and Lower group by a series of sandstones and shales (Calp), and the Carboniferous slate (5,000 — 6,000 ft. thick) is entirely absent; while there is a development of thick sandstones at the base of the coal measures in the N., resembling the Millstone grit of Derbyshire. The coal measures probably at one time covered all the Carboniferous limestone, patches being still left, forming hills above the limestone plain.

Rock characters of Carboniferous limestone. Crystalline limestone, frequently built up of Corals, Crinoids, or shells. Sometimes oölitic and often traversed by calcite veins and bands of chert. The "Fusulina" limestone, which covers an immense area in Russia, S. Alps, Spain,

America and the United States is of this age, and is built up of the shells of one of the earliest types of Foraminifera.

Fossils.	Corals.	Lithostrotion basaltiforme, Amplexus coralloides, Lonsdaleia floriformis, Michellinia favosa.
	Echinoid.	Palæchinus sphericus (first Echinoid).
	Crinoidea.	Woodocrinus, Platycrinus, Cyathocrinus, Actinocrinus.
	Blastoid.	Pentremites.
	Crustacean.	Phillipsia (last of the Trilobites).
	Brachiopoda.	Productus giganteus, P. semi-reticulatus, P. hemisphericus, Spirifera striata, S. glabra.
	Gasteropod.	Euomphalus pentangulatus.
	Cephalopod.	Nautilus bi-angulatus.

Millstone grit. Few fossils, chiefly plant remains. It gives barren soils, and is useful only for building purposes, millstones etc.

Rock character of Coal measures. A series of sandstones, shales, ironstones and thin seams of coal. Towards the W., the S. Wales coal strata become violently contorted and anthracitic, there being a connection between the heat that produced metamorphism and the lateral pressure producing contortion; for pressure is convertible into heat. Anthracite also occurs in the disturbed and contorted strata of Pennsylvania.

Causes of the separation of Coal fields.

1. Denudation of an anticlinal, as in the Lancashire and Yorkshire coal fields.
2. By the covering up of portions by younger deposits, so that they form inliers, as in the Midland coal fields.
3. By forming outliers, as in Ireland.

There is reason to believe that a large part of the British Isles was once covered by Carboniferous strata. Judd found an isolated patch in the Highlands of Scotland. Possibly patches may still be left covered up by newer strata in the S. E. of England, lying in synclinal hollows of the Palœozoic rocks. This probability is strengthened by the fact that coal reappears in Belgium and N. France, and that in the Bas Boulonnais the Carboniferous limestone has a S. dip under Oölitic and Wealden strata. Probably the remarkable scattered coal basins of France and central Germany were, from the first, isolated areas of deposit.

Proofs of the vegetable origin of coal.

1. Impressions of leaves are abundantly found in the overlying shales.
2. Roots of trees are found in the under-clay.
3. In the coal itself are found the carbonised remains of stems.
4. Microscopic sections of many coals (cannel) show the colapsed spore-cases of *Lycopodiaceœ etc.*
5. The older parts of the peat now forming in marshes, have become turned into an imperfect coal.

Mode of accumulation of coal strata.

The under-clay formed the soil upon which grew a luxuriant vegetation, consisting chiefly of *Lycopodiaceœ*, *Equisetaceœ* and *Ferns*; by the decay of which, material was supplied for the production of coal. Subsidence of the land led to the destruction of the forests and the covering up of the vegetable matter with mud and sand. By a repetition of this process each seam of coal was formed. The number of successive pauses and subsidences is shown by the number of beds of coal (80 in Wales), and the great duration of each forest growth by the thickness of the seams. In S. Staffordshire one seam is more than 30 ft. thick.

Mineralisation of coal.

When woody vegetable matter is buried in the earth and partially or entirely excluded from the air. it decomposes slowly and evolves Carbonic acid. By this means it is gradually converted into *lignite* or *brown coal.* This lignite, chiefly by discharge of Carburetted hydrogen, turns into *coal.* This coal is bituminous, but by a further chemical change it becomes smokeless or *steam coal,* and by a still further change, anthracitic or non-bituminous. The conversion of wood into coal consists of a gradual diminution in Oxygen and Nitrogen, with a consequent increase of Carbon, the Hydrogen remaining nearly constant.

Relation of Carboniferous vegetation to existing flora.

Carboniferous flora seem to be uniform over a much wider area than plants of the present day, similar plants being found in the coal measures of Britain, Bear I^{s}., N. and S. America, S. Africa and Australia. This points to a more uniform climate, and to the ease with which spores may have been transported by wind. The flora consists chiefly of *Acrogenous Cryptogams.* The Carboniferous *Lycopods* were often 50 ft. high, whereas the largest now living in New Zealand are not more than 3 ft. high, and the club-mosses of Britain are still more insignificant. Living *Equisetaceœ* are not more than 15 ft. high, while those of the coal measures ranged from 30 to 50 ft., and were much more highly developed. The *ferns* somewhat resemble tropical species now existing. A few *Phanerogams* existed in Carboniferous times, chiefly *Conifers* and *Cycads.* The Monocotyledon *Pothocites Grantoni* of the coal measures, is the first true flowering plant, allied to the *Arum* or " Trumpet-lily " of the green-house.

Fossils of the coal measures.

Lycopodiaceæ.	Lepidodrendron, & its fruit Lepidostrobus.
	Sigillaria, , , Stigmaria.
Equisetaceæ.	Calamites, Asterophyllites.
Filices.	Pecopteris, Neuropteris, Sphenopteris.
Crustacean.	(Merostomata). Prestwichia anthrax (*Xiphosura*).
Lamellibranchiata.	Aviculopecten papyraceus, Anthracosia (Unio).
Gasteropod.	Pupa vetusta (air breathing).

Cephalopoda.	Goniatites Listeri (forerunner of Ammonites).
Fish.	Abundant remains of teeth, especially in Scotland.
Amphibians.	Labyrinthodont foot-prints.

The presence of marine intercalations in the coal measures, with *Aviculo-pecten*, *Goniatites* etc., proves the occasional invasion of the sea.

Volcanic action. The Old Red Sandstone volcanoes of Scotland had by this time dwindled down to innumerable small vents, the remains of which are still to be found in the central valley. In Derbyshire, sheets of contemporaneous lava, called "Toad-stones", are found in the Carboniferous limestone. Lavas of this age also occur in Devonshire and the Midland counties.

Economic products. The Coal measures, besides coal, yield bands of clay-ironstone, the source of much of our iron. The Carboniferous limestone and Millstone grit, are much used for building purposes, and the former contains valuable veins of zinc, lead and hæmatite.

Coal fields which are not of Carboniferous age.

In *Great Britain* coal is worked in the *Inferior Oölite* at Brora and Skye, and in the *Lower Oölite* of Yorkshire.

In *Europe* the Brown coal of N. W. Germany, Bohemia, Transylvania and Croatia is *Tertiary.* Round Hanover and in Catalonia the coal is *Neocomian*, (but in the Asturias it is *Lower Carboniferous*).

Coals of Jurassic age are worked at Fünfkirchen in Hungary, and in the *Jurassic* and *Lias* of Germany. Impure *Brown* coal in the *Keuper* of Germany. Thin seams of coal occur in the *Permian* of Russia.

In *Asia.* Assam has *Lower Tertiary* coal. India has Mesozoic coal (probably *Jurassic*). Australia, Tasmania and New Zealand have *Mesozoic* coal.

5. *Permian period.*

Although in some lcoalities the Permian beds seem conformable to the Coal measures, yet on the whole they are considered unconformable. Lithologically they cannot be separated from Triassic rocks lying above them, and some geologists have, therefore, classed the Permian and Trias together under the term *Poikilitic* (variegated). In this case the Permian would rank with Mesozoic rocks, but their marine fauna so closely resembles the Carboniferous, that it is better to place them at the top of the Palœozoic series. At the same time it must be remembered that nowhere has more difficulty been encountered than in the separation of Palœozoic from Mesozoic time.

On the Continent this formation consists of two divisions (hence called Dyas) viz.

Zechstein group — Dolomite, shales and sandstone.
Rothtodtliegende group — Sandstones, shales and conglomerates.

In England a triple division can be made as follows :—

		Thickness in feet	
		in W. England,	in E. England.
Upper.	Red sandstones, clays & gypsum.	600.	50 — 100.
Middle.	Magnesian limestone, & marl-slate.	10 — 30.	600.
Lower.	Sandstones and marls, with calcareous conglomerates and breccias at the base.	3000.	100 — 250.

Localities. Eden valley, Whitehaven, and on the borders of the Lancashire, N. Wales, Shropshire, and Midland coal fields. The Magnesian limestone extends in a narrow strip from Durham to Nottingham. In Russia, beds of Permian age, similar to those of W. England, cover thousands of square miles, the name Permian being derived from Perm in E. Russia, where they were originally worked by Murchison. In the Harz Mts., Saxony and Bohemia, the Permian strata resemble those of England.

Mode of formation of Permian strata.

It is probable that the Permian strata were deposited in inland salt lakes, like the Caspian, for the following reasons : —

1. The poverty and dwarfed nature of the fossils.
2. The occurrence of beds of gypsum, and pseudomorphs of rock-salt.
3. The abundance of foot-prints of Amphibia and land reptiles.
4. The presence of Magnesian limestone (see Dolomite).
5. The abundance of plant remains showing great resemblance to those of coal measures.

Ramsay considers that the breccias are due to glacial action.

Fossils. The Upper Permian has yielded no fossils. and the Lower Permian contains chiefly terrestrial remains, such as *Lepidodendron*, *Calamites* and *Labyrinthodont* remains.

The Middle Permian contains —

Polyzoa.	Fenestella retiformis.
Brachiopoda.	Productus horridus (Productus is now dying out), Spiriferina (only Permian form characteristic of Mesozoic). Spirifera alata, Lingula Credneri.
Lamellibranchiata.	Schizodus Schlotheimi.
Fish.	Palœoniscus comptus and P. elegans (closely related to Carboniferous).

Volcanic action. Some of the volcanic rocks of Devonshire are probably of this age. Sheets of contemporaneous lava (porphyrite) occur in the basin of the Nith and in Ayrshire. Great masses of eruptive rocks are found also in Bohemia and Moravia. Ramsay is of opinion that the basalt, etc., of S. Staffordshire, Coalbrook Dale, Clee Hills and Warwickshire may be of Permian age.

Economic products. Magnesian limestone when well selected, forms one of the best building stones in England. Some of it is used for the production of Carbonate of Magnesia and Epsom salts.

MESOZOIC TIME.

1. *Triassic period.*

The Trias is so called because in Germany it is divisible into three groups as follows:—

Keuper.	Red marls with rock-salt and gypsum, passing into sandstones with a breccia at the base.
Muschelkalk.	Shelly limestone with beds of dolomite, gypsum and rock-salt — *Absent in England.*
Bunter.	Variegated sandstones, with pebble beds in the middle.

These beds rest unconformably upon the Permian and underlying strata.

Localities. Triassic rocks occupy a large area in the centre of England, whence they branch N.E. to Hartlepool, N.W. to Lancaster and S. to S. Devon. They thin out towards the S.E. (confirmed by their non-occurrence at Harwich or Calais) indicating land in that direction. They may also be found in the Vale of Clwyd and near Belfast, much of the Irish sea and the Bristol Channel being probably filled with them.

On the *Continent* there are two typical areas, one in Germany and France, resembling English Trias (except in having Muschelkalk); the other on the S.Alps and the Austrian Tyrol, differing in the following points:—

1. Total difference of lithological character (great masses of dolomite).
2. Much interstratified and intrusive volcanic rock.
3. Its great extent.
4. Palœontological peculiarities (marine species extremely abundant).

Triassic rocks also occur in the United States, Asia and Australia.

Mode of formation of Triassic rocks.

That the English and German Trias were, like the Permian, deposited in inland seas is proved by the following facts: —

1. Ripple marks, rain prints, sun cracks, Annelid tubes and Labyrinthodont tracks show proximity of land.
2. The occurrence cf rock-salt and gypsum.
3. The paucity of organic remains.

In Bristol and Somerset there is a dolomitic conglomerate lying in patches on the Palœozoic rocks at different heights above sea level. These may be the remains of old shingle beaches in the early part of the Keuper period.

Fossils. English beds are almost unfossiliferous.

Bunter and Keuper groups.

Plants.	Conifers (Voltzia), Equisetaceæ (Calamites), Cycads.
Crustacea.	(Phyllopoda) Estheria minuta.
Fish.	Hybodus, Acrodus.
Reptilia.	Labyrinthodon, Rhyncosaurus, Palœosaurus (dolomitic conglomerate).
Mammalia.	Microlestes antiquus (marsupial). *First mammal* (Keuper of the Continent).

Muschelkalk group.

Crinoidea.	Encrinus liliiformis (very characteristic).
Brachiopoda.	Terebratula vulgaris.
Lamellibranchiata.	Lima striata.
Cephalopoda.	Ceratites nodosus (link between Goniatites and Ammonites).

Economic products of the Trias. The Upper Keuper (Saliferous marls) contain beds of rock-salt in Cheshire and Worcestershire. At Northwich there are two thick beds of salt, one 90, and the other 150 ft. thick, separated by 30 ft. of red clay. Gypsum is also abundant. The marls yield a rich soil, well suited for orchards, and the sandstones are quarried for building purposes.

Rhœtic beds.

The Rhætic or Passage beds form a perfectly conformable passage from Trias to Lias. In England they are never more than 100 ft. thick, but in the Rhætian Alps they attain a thickness of 3000 ft.

Rock character. Cream coloured limestone (White Lias), passing down into black shales and bone beds.

Localities. They extend between the Lias and Trias in patches from Redcar (Yorks.) to near Lyme Regis (Dorset); best seen at Westbury on Severn, Penarth in Glamorganshire (hence called Penarth beds), near Tewkesbury and Stratford-on-Avon. The Portrush beds of Ireland are of this age. On the Continent Rhætic beds stretch from Geneva to Vienna.

Fossils.	Phyllopod Crustacean.	Estheria minuta.
	Lamellibranchiata.	Avicula contorta [hence often called Avicula contorta beds], Cardium Rhæticum, Pecten Valoniensis.
	Fish and reptiles.	Similar to Trias.
	Mammal.	Microlestes Rhæticus.

The continental Rhætics are marine, the English shallow water, showing gradual subsidence of the land beneath the Liassic sea.

2. *Jurassic or Oölitic period.*

(a). *Lias (layers).*

		Ammonite zones.
Upper Lias.	Bluish clay, with nodules of limestone.	A. Jurensis. A. communis. A. serpentinus.
Middle Lias or Marlstone.	Upper part "Rock bed" or marlstone proper, ferruginous.	A. spinatus. A. margaritatus.
	Lower part, micaceous sands and clays.	A. Henleyi. A. ibex. A. Jamesoni.
Lower Lias.	Upper part consisting of clay, occasional bands of limestone. Lower part, argillaceous limestone (hydraulic) with partings of clay or shale	A. raricostatus. A. oxynotus. A. obtusus. A. Turneri. A. Bucklandi. A. angulatus. A. planorbis.*

* White Lias.

Localities. From Lyme Regis to Whitby in a narrow band; an outlier occurs lying unconformably on Triassic beds at Carlisle. Liassic rocks are found also in Skye, W. Scotland and N. Ireland, and on the Continent in the Jura Mts.† and N.W. Germany. The Ammonite zones are persistent over England, Germany and France. In America the Lias plays a very subordinate part.

† There is a marked unconformability between the Lias and Oölite in the Jura Mts.

Mode of formation. Marine deposit, but formed near the shore. This is proved by the plant and insect remains found especially in the Lower Lias. The "Insect limestone" of Gloucestershire and Warwickshire, occurring just above the zone of A. Planorbis, contains 24 families of insects with many land plants.

Ramsay considers that the Liassic strata were deposited in warm seas, surrounding an Archipelago, of which Dartmoor, Wales and Cumberland were islands. Ansted thinks the conditions resembled those on the E. coast of Asia, where rivers running over extensive flats, pour their waters into a sheltered portion of the ocean.

The occurrence of the argillaceous limestone, which can scarcely be of organic origin, is remarkable.

Fossils.	Corals (scarce).	Montlivaltia.
	Crinoidea.	Pentacrinus basaltiformis, Extacrinus briareus.
	Brachiopoda.	Spiriferina Walcottii (end of the Spirifers), Rhynchonella tetrahedra.
	Lamellibranchiata.	Gryphæa incurva, Lima gigantea, Hippopodium ponderosum, Cardinia Listeri, Pholadomya ambigua.

Cephalopoda.	Ammonites (see zones). Belemnites elongatus.
Reptilia.	Icthyosaurus, Plesiosaurus. (Reptiles very characteristic).

Economic products. The Lower Lias is much quarried both for building stone and lime burning, as well as for the manufacture of hydraulic cement. The clays are often used for brick and tile making.

The Middle Lias of Yorkshire has a bed of argillaceous Carbonate of iron, 15 to 20 ft. thick, and worked extensively in the Cleveland district.

The Upper Lias yields jet at Whitby.* The alum shale of Yorkshire occasionally contains alum efflorescent on the surface; but generally it contains only the constituent parts from which alum can be manufactured.

* Jet is a fossilised coniferous wood.

(b) Oölite period.

Upper Oölite.	Purbeck beds. Portland stone. Portland sands. Kimmeridge clay.	
Middle or Oxford Oölite.	Coral rag. Oxford clay with Kellaways rock.	
Lower or Bath Oölite.	Cornbrash.	
	Forest marble (local). Bath Oölite. Stonesfield slate (local).	Great Oölite.
	Fuller's earth (local). Inferior Oölite.	

Typical Sections of Lower Oölites in England.

S.W: England.	N. Oxfordshire & S.Northants.	N. Northants & S. Lincolnshire.	Yorkshire.
6. Cornbrash.	6. Cornbrash.	6. Cornbrash.	6. Cornbrash.
5. Forest marble & Bradford clay. 4. Great Oolite with Stonesfield slate at base.	5 4 3 2 1 Gt. Oolite (upper zone). Northampton sands = Lower zone of Great Oolite and part of Inferior Oolite.	5 4 Gt. Oolite clays. Gt. Oolite limestone. Upper Estuarine series.	5. Upper shale and sandstone (Upper Estuarine). 4 3 2 Scarboro' limestone. Middle shale & sandstone with Moorland coals (Mid. Estuarine). Millepore bed. Lower shale and sandstone, [Lower Estuarine].
3. Fuller's earth. 2. Inferior Oolite. 1. Midford sands.		2 1 Inf. Ool. limestone or Lincolnshire oolite with Collyweston slate at base, Northampton sands, including Lower Estuarine series.	2 1 Dogger series.
Upper Lias clay.	Upper Lias clay.	Upper Lias clay.	Upper Lias clay.

Localities. Fringing the Lias, in a varying band, from Portland to Yorkshire. They occur also in France, N.W. Germany, the Alps and Rocky Mts., as well as in India and Australia.

Rock characters. Sandstones, clays and limestones. The alternation of limestones and clays illustrates the influence of geology upon scenery, the limestones forming escarpments, and the clays forming valleys between them. Typical Oölitic limestone consists of rounded grains of Carbonate of Lime, having a central nucleus generally of sand. From this egg-like structure the name has been given.

Mode of formation. Owing to minor changes the physical geography, the Lower Oölites were locally broken up into marine, estuarine, freshwater and even terrestrial beds; marine in Dorset, Somerset and Gloucester, partly passing into estuarine and freshwater strata in Northants, and in Yorkshire showing a miniature coal field and alternations of terrestrial and aquatic conditions. The Middle Oölite shows marine conditions in coral reefs. The Upper Oölite were also marine. So that while from Gloucestershire to the S., the whole of the Oölitic series is marine, we find on going N., the Lower Oölite gradually assume an estuarine and terrestrial character.

Fossils. *Lower Oölite.*

Echinodermata.	Clypeus Plotti, Apiocrinites rotundus.
Brachiopoda.	Rhynchonella spirosa, R. concinna, Terebratula fimbria.
Lamellibranchiata.	Trigonia cestata, Pholadomya fidicula, Ostrea acuminata *(Fuller's earth)*, O. flabelloides.
Gasteropoda.	Pleurotomaria ornata.
Cephalopoda.	Ammonites Humphreysianus, A. Parkinsoni.
Mammalia.	(Stonesfield slate) Amphitherium, Phascalotherium, Stereognathus, *(marsupials)*.

*Middle Oölite.**

Corals.	Isastræa explanata.
Echinodermata.	Cidaris florigemma.
Lamellibranchiata.	Gryphæa dilatata, Ostrea gregaria.
Gasteropoda.	Chemnitzia Heddingtonensis.
Cephalopoda.	A. Jason, Belemnites hastatus.

Upper Oölite.

Corals.	Isastræa oblonga (preserved in flint).
Brachiopoda.	Rhynchonella inconstans.
Lamellibranchiata.	Trigonia gibbosa, T. incurva, Ostrea deltoidea, Exogyra virgula.
Gasteropoda.	Cerithium Portlandicum.
Cephalopoda.	Ammonites biplex, A. triplex.

* The Solenhofen limestone (Middle Oölite) contains the oldest known bird, *Archæopterix*, and many winged reptiles (*Pterodactylus crassirostris*).

Purbeck beds. These beds are placed by most authors at the top of the Jurassic series, although their general character shows a strong resemblance to the freshwater conditions of the Wealden beds. They derive their name from the Isle of Purbeck, where they consist of —

1. *Upper freshwater group* (Purbeck marble) containing Paludina, Limnœa, Planorbis, Cyclas, Unio, with Cyprides.

2, *Middle division*, containing marine "Cinder" beds, full of Ostrea distorta, also brackish and freshwater beds with mammalian remains, amongst which are Plagiaulax, Spalacotherium and Amphitherium.

3. *Lower freshwater group*, with Dirt beds containing many trunks of Conifers and Cycads (Mantellia nidiformis).

Traces of Purbeck beds also occur near Battle (Sussex) and at Brill (Bucks), Swindon and Hartwell.

Economic products. The Northampton sands yield iron ore in workable quantities. Good building stones are obtained from the Inferior, Bath and Portland Oölites. Fuller's earth used to be employed more extensively than now in cloth mills. Stonesfield slate is quarried both for roofing purposes and for building stone. Coral rag is quarried but is not very durable. The Kimmeridge clay contains bituminous shales, which have been used in the manufacture of mineral oil. Distinct coal seams occur in the Lower Oölite of Yorkshire and Brora.

Purbeck marble was formerly much used in churches.

3. *Cretaceous period.*

		Palæontological zones.
Upper.	Upper Chalk (with flints)	Senonian.
	Lower Chalk (without flints)	Turonian
	Chalk marl.	and
	Upper Greensand and Chloritic marl.	Cenomanian.
	Gault.	Gault.

		Fluviatile type.		*Marine type.*	
Lower.		Wanting.	Lower Greensand.	Folkstone beds. Sandgate beds. Hythe beds & Kentish Rag. Atherfield clay.	Upper Neocomian.
				Speeton clay.	
		Weald clay.		Punfield beds. Tealby series. Speeton clay (part).	Middle Neocomian.
	Hastings sands.	Tunbridge Wells sand. Wadhurst clay. Ashdown sand.		Speeton clay (part).	Lower Neocomian.
		Purbeck beds.			

Localities. Cretaceous rocks cover much of the E. and S.E. of England, occurring in Yorkshire, Lincolnshire, Norfolk, Suffolk, Essex, Cambridge, Herts., Beds., then dipping below the London area, and re-appearing in the N. Downs and extending through the Chiltern hills, Berks., Wilts., Dorset., Hants. to the S. Downs of Sussex.

On the Continent they occur in France, Belgium, Germany, Switzerland and on both sides of the Mediterranean basin. They cover large areas also in Asia Minor, Persia, and patches occur in the Himalayas. The famous Deccan basalts are of this age. Cretaceous rocks occur also in Australia, New Zealand and N. America.

Hastings sands form the central portion of the Wealden area and contain remains of *Iguanodon* and other reptiles, with freshwater molluscs.

Weald clay occurs surrounding the Hastings sands of the Wealden area, and in the I. of Wight. It contains bands of freshwater limestone (Sussex marble) full of *Paludina fluviorum.*

Lower Greensand. The Atherfield beds consist of clay, with phosphatic nodules near Pulborough. The Hythe beds contain sandy limestones, called Kentish Rag, very suitable for hop growing. The Folkstone and Sandgate beds are false-bedded sands.

The most important fossils are —

Spongida.	Manon.
Crustacea.	*(Macrura)* Meyeria Vectensis.
Brachiopoda.	Terebratula sella.
Lamellibranchiata.	Pecten cinctus, Perna Mulleti.
Cephalopoda.	Ammonites Deshayesii, Ancyloceras gigas.

Gault. Stiff blue clay with —

Brachiopoda.	Terebratula biplicata.
Gasteropoda.	Rostellaria carinata.
Lamellibranchiata.	Inoceramus sulcatus, Nucula pectinata.
Cephalopoda.	Ammonites splendens, A. lautus, Hamites intermadius.

Upper Greensand. Sands and sandstones, coloured green with Glauconite (with casts of Foraminifera) containing —

Spongida.	Siphonia pyriformis.
Lamellibranchiata.	Pecten asper.

N.B. The Chloritic marl of Cambridgeshire is homotaxial with the Upper Greensand, but derived from denudation of the beds below.

Chalk. (For origin of flint see "Notes on Segregation").

The White chalk ranges from Ireland to the Crimea. The oldest beds of the Chalk are represented by the Hippurite limestone, which occurs in S. France, Spain, Italy and Greece. Hippurites were exclusively Cretaceous molluscs, allied to the Chama, so abundant amongst the coral reefs of the present day.

Fossils. U. = Upper, L. = Lower Cretaceous.

Spongida.	Ventriculites.	U.
Echinodermata.	Ananchytes ovatus.	U.
	Micraster cor-anguinum.	U.
	Galerites albo-galerus.	U.
Brachiopoda.	Terebratula carnea.	U'
Lamellibranchiata.	Lima spinosa.	U.

Lamellibranchiata.	Inoceramus mytiloides.	L.
	Pecten Beaveri.	L.
Cephalopoda.	Ammonites varians.	L.
	A. Rhotomagensis.	L.
	Scaphites æqualis.	L.
	Turrilites costatus.	L.
	Hamites armatus.	L.
	Belemnitella mucronata.	U.
	Baculites anceps.	L.
Fish.	Ptychodus.	L.
	Beryx.	

N. B. The Hunstanton Red Chalk is generally believed to be of the age of the Gault.

Origin of the White Chalk. The similarity of the Atlantic Ooze to the Chalk formation has given rise to the question whether the Chalk period has not continued to the present time.

Arguments concerning the continuity of the Chalk to the present time.

In favour of this view.	*Against this view.*
1. There is a great deal of resemblance between Chalk and Atlantic Ooze.	1. Chalk contains much less clay than the Ooze.
2. Existing Foraminifera are to a large extent identical with Cretaceous forms.	2. Low forms of life have great power of 'living on' through great geological changes, e.g. Lingula (Cambrian to Recent).
3. The Ooze contains sponges comparable with Cretaceous forms.	3. Besides we do not found our great divisions of strata on foraminifera, sponges, echinoids, corals, but on the most highly organised species available, e.g. mollusca.
4. The Ooze contains Echinoids and Crinoids such as abounded in the Chalk period.	4. The most characteristic chalk fossils are Brachiopods and Cephalopods, which are not characteristic of the Ooze.
5. The conditions of formation were probably somewhat similar.*	5. Littoral fauna are more likely to change than deep sea fauna; since whole ocean beds are not often elevated at once; the maritime life necessarily extends on into the next period.

* Note. Probably Chalk was deposited in an inland European sea, perhaps never deeper than 1000 fathoms, somewhat in the same way as the deposits now forming near Florida, and in the Gulf of Mexico, where a soft white lime-mud extends over the whole bed of the Gulf Stream. This view is confirmed by the fact that the oozes of shallow water resemble chalk much more than do those of water over 1000 fathoms deep, as well as by the fact that all the Chalk genera are shallow water forms.

Economic products. The Hastings beds are often hard enough for road-metal. Weald clay contains the Sussex marble, useful for building. The Speeton clay yields large quantities of *Septaria*, which are used in making Roman cement. Kentish Rag is used for building purposes. Phosphatic nodules are dug in the Lower Greensand, in which also iron ore is abundant, and was formerly extensively worked. The Chalk is sometimes hard enough to form building stone (the so called Totternhoe stone), but is chiefly used for lime burning, the flints being useful for road-metal, and, when ground, for pottery mixtures.

Beds between Cretaceous and Eocene.

At *Maestricht*, resting unconformably on the Chalk, is a calcareous formation, the unconformity being marked by a layer of water worn flints. These beds contain Baculites and Hamites (not yet found in Tertiary strata), together with Voluta and other genera of Eocene type. The huge saurian Mosasaurus is found here. Around Paris are smaller patches of *pisolitic limestone*, once united, but now separated by denudation. These contain both Cretaceous and Eocene species. At *Faxoe* (Denmark) there is a yellow limestone so full of corals that it was evidently once a coral reef. It contains many univalves unknown or rare in the Chalk, such as Cypræa, Oliva; with these occur Baculites, Belemnitella and Nautilus Danicus, which are unknown in European Eocene; although a Belemnite is said to have been found in the late Tertiary strata of Australia.

CAINOZOIC TIME.

1. *Eocene period.*

A great lapse of time is indicated between the Eocene and Cretaceous periods, both by a great palæontological break, as well as by the fact that the lowest Eocene beds rest upon an eroded surface of chalk.

The typical Eocene beds occur in synclinal hollows in the Chalk, in three basins, as follows:—

	Hampshire basin.	*Paris basin.*	*London basin.*
Upper.	Upper Bagshot sands.	———	Upper Bagshot sands.
	Barton clay.	Beauchamp sands.	
Middle.	Bracklesham sands.	Calcaire Grossier.	Middle Bagshot sands.
	Lower Bagshot sands.	———	L. Bagshot sands.
Lower.	London clay (Bognor beds).	Soissonais sands.	London clay.
			Oldhaven beds.
	Woolwich and Reading beds.	Argile plastique.	Woolwich and Reading beds.
		Sables de Bracheux.	Thanet sands.

Strata of Eocene age range from S. Europe to China and Japan, and occur also in N. America.

Thanet sands thin out to N. and W. of London; thickest to S. and E. At the base is a layer of unworn green-coated flints. Whitaker says that the eroded surface of the chalk only occurs where the overlying beds are thin, and does not necessarily point to an unconformity, but has been formed by infiltration of water since the Thanet sands were deposited. Fossils scarce, marine deposit.

Woolwich and Reading beds. Wedge shaped interstratifications of mottled clays, sands and pebble beds, uniting marine, estuarine and freshwater conditions.

Fossils.	Lamellibranchiata.	Cyrena cuneiformis.
		Ostrea bellovacina.
	Gasteropoda.	Melania inquinata.
		Cerithium funatum.

London clay. At the base of the London clay are the Oldhaven pebble beds, usually classed with the preceding beds.

The London clay is a bluish tenacious clay, weathering brown, with septarian nodules of hydraulic limestone. These strata were deposited in the estuary of a great continental river similar to the Amazon or the Ganges. The proximity of land is proved by the abundance of crocodiles and turtles, and the pyritised remains of plants such as palms (Nipadites), acacia, coniferæ and Proteaceæ similar to Australian genera. The tapir like animals are allied to the tapirs of S. America.

Fossils.	Lamellibranchiata.	Panopœa intermedia.
		Pectunculus brevirostris.
	Cephalopoda.	Nautilus centralis.
		Belosepia sepiodea.
	Fish.	Lamna. Otodus (sharks).

Lower Bagshot. Variegated sands of Alum bay and Bournemouth (with leaf beds) and sands of Hampstead.

Bracklesham beds. Clays and sands with seams of lignite full of Cardita planicosta and Nummulites lævigatus (Foraminifer).

Barton clay. Very full of: —

Fossils.	Lamellibranchiata.	Crassatella sulcata.	Chama squamosa.
	Gasteropoda.	Voluta ambigua.	Rostellaria ampla.
		Fusus porrectus.	Murex asper.

Upper Bagshot sands. Sands with very few fossils.

The Nummulite limestone, corresponding to Bracklesham beds of England, extends 4000 miles from the Pyrenees to Italy, Greece, the Crimea, Persia, Central Asia and China. In the Pyrenees it is 4000 ft. thick. The Egyptian pyramids are built of it. In the Aguille d'Or it is 11,500 ft.

Economic products. The clays are used for brick making. Some useful beds of pipe clay occur. The Septaria from the London clay are largely used for making cement.

2. *Oligocene period.*

The Oligocene or Fluvio-marine series of the Hampshire basin were formerly called Upper Eocene. They have been considered of late to include also some deposits formerly regarded as of Lower Miocene age. As this question is scarcely yet settled, the following classification will be here adopted.

	Hampshire basin.	*Paris basin.*
Upper.	Wanting.	Beauce limestone.
Middle.	Hempstead beds. Bembridge limestone and marl.	Fontainebleau sands. Gypseous marls of Montmartre.
Lower.	Osborne or St. Helen's beds. Headon & Brockenhurst beds.	Siliceous limestone.

Geikie also refers to this age the Bolderberg and other Belgian deposits, the Lower Molasse of Switzerland, the lacustrine deposits of Auvergne, the lower deposits of the Vienna basin, the Brown coal formations of Bonn and Croatia, as well as the leaf beds of Bovey Tracey, Antrim and Mull. These will be described under Miocene deposits.

Headon beds. Upper and *Lower*. Marls and freshwater limestones, with:— Gasteropoda. Limnœa longiscata. Planorbis euomphalus.
Paludina lenta. Cerithium concavum.
Plant. Chara.

Middle. Marine sands with Cytherea incrassata, and oyster bed.

Osborne beds, comprising Nettlestone grits underlying St. Helen's sands. Fossils like freshwater Headon.

Bembridge limestone and marl.
Fossils. Gasteropoda. Bulimus ellipticus. Helix occlusa.
Melania turritissima.
Mammalia. Anoplotherium (pig-like). Palæotherium (tapir-like). Chœropotamus (river hog).

Hempstead beds. Lyell classed these as Lower Miocene, since Heer found four species of plants like those of the lignite of Bovey Tracey. Otherwise they resemble the Fluvio marine series just described. They consist of clays and marls with Corbula pisum.

Economic products. Bembridge limestone was once largely quarried.

3. *Miocene period.*

Miocene formations are almost entirely absent from the British Isles.

Upper Miocene. Wanting in Britain.

Lower Miocene. Leaf beds of Bovey Tracey, Mull and Antrim.

Lower Miocene. (Upper Oligocene of Geikie). In a lake-like depression at Bovey Tracey is a group of sand, clay and lignite beds, containing remains of plants, indicating sub-tropical vegetation, and closely resembling Lower Miocene flora of Switzerland. In the sea-cliffs of Mull are leaf beds, covered with Basalt and interstratified with tuff. The plants are of Miocene age, but of a more N. type than those of Bovey. Similar beds occur at Antrim. Associated with the volcanic rocks of Skye and the Faroe Islands a similar vegetation is found, but of a still more N. type. The volcanic eruptions of Iceland date back to the Miocene period, while one of the most remarkable geological discoveries of recent times is that of Miocene plant beds in N. Greenland, and a bed of coal 30 ft. thick in Disco Island. The plants include Sequoia, beech, oak, poplar, maple, walnut, lime etc. This occurrence of a luxuriant vegetation within 8 deg. 15 min. of the N. Pole, where darkness now prevails for half the year, and the ground is almost always covered with snow and ice, is a striking illustration of the great changes in climate which the N. Hemisphere has undergone.

In *Auvergne,* lacustrine strata occur of Lower Miocene age with remains of mastodon, rhinoceros, elephant, tapir etc.

In *Switzerland* the Lower Molasse consists of fluvio-marine beds with an abundant flora indicating a warmer climate and containing palms, Banksia (now in Australia), Sequoia, Proteaceæ, figs; the whole of an American type. The *Brown coal* of Bonn, and the coal beds of Croatia with date palms, are of this age. In Hungary and Transylvania there is evidence of immense outpouring of lavas.

Upper Miocene. In the Loire district, the Faluns of Touraine are shallow sea deposits, made up to a great extent of broken shells and corals, and containing remains of Dinotherium, Mastodon, Rhinoceros, Hippopotamus, and shells, 15 per cent. of which are common to the crag, among them Voluta Lamberti. Somewhat similar deposits occur in S. France, near Bordeaux.

In Switzerland, the Œningen beds consist of soft sandstone (Molasse) in three divisions, of which the middle alone is marine, and the lower is described above (Lower Miocene). The Upper Molasse contains maples, planes, and walnuts of a N. American aspect, together with mastodon, a huge salamander and many species of insects.

Vienna basin. Marine strata with Gasteropoda now living in the Indian Ocean, and mammalian remains as above.

Italy and Greece. The Upper Miocene fauna indicates vast grassy plains, where rugged mountains now exist in Greece, and probably extending over the Ægean to Asia Minor. Giraffe, Antelope, Hipparion, Dinotherium and Mastodon are found.

Upper Miocene strata occur in the Siwalik Hills, India, and in N. America.

Physical Geography in Miocene times. During this period, the British Isles formed part of a large continent, embracing Ireland, and spreading far N. and W. into the Atlantic, and united in the S. with Africa. The Alps, Carpathians and Pyrenees now first rose into prominence as mountain chains. The English Miocene and most of the Sw

Miocene are of lacustrine origin; but the great Swiss Miocene lake underwent gradual subsidence, so that the sea gained occasional admission. Contemporaneously one or more large sheets of fresh water lay in the heart of France. These appear to have been destroyed by volcanic explosions, which afterwards poured out great sheets of lava and formed the cones and puys of Auvergne. The sea stretched across the S. of France, and also ran up the present valley of the Danube to the foot of the Alps.

In Antrim, and the N. W. of Scotland, the great terrestrial volcanoes, which had begun in Eocene times, increased in activity, and, in the intervals of eruptions, lakes were sometimes formed in which leaf-beds accumulated.

The Eocene lavas were acid, and, before the deposition of the basic Miocene rocks upon them, underwent immense denudation, showing a long period of quiescence. The chief centres of volcanic activity were Antrim, Mull, Skye, Rum, Airdnamurchan and St. Kilda, each of which rivalled Etna, and formed only part of a long chain extending from Iceland, by the Faröe Islands and Cape de Verd, to Tristan d'Acunha. As in Auvergne, these huge volcanoes dwindled down in Pliocene times to spluttering "puys". In the Eifel district, Hungary and Transylvania, also, volcanic action began in this period and continued to Pliocene times.

Doubtless huge mammals inhabited England. Their remains are not found in English Miocene deposits, although there is a commingling of Miocene and Pliocene types in beds at the base of the Crag.

The American nature of the flora has been explained by Forbes on the supposition of a Miocene 'Atlantis', over which the plants travelled; but it is now believed that they came by Behring's Straits and Asia, since the more we travel E. the more does vegetation put on a Miocene character.

Economic products. "Bovey Coal" has been extensively used for fuel. The clay beds are used for pottery, and large quantities are shipped at Teignmouth.

4. *Pliocene period.*

Newer Pliocene.	Bure valley beds and Cromer Forest-bed. Chillesford clay and sand. Norwich (fluvio-marine, mammaliferous) Crag.
Older Pliocene.	Red Crag. White or Coralline Crag.

Localities. Norfolk and Suffolk, France, Belgium, Germany, Italy, Greece, India, N. America, Australia and New Zealand.

Coralline crag consists of sand and comminuted shells, often false-bedded, with many Polyzoa, but rarely true Corals. At the base there is a coprolite bed. Sixteen per cent of the mollusca are extinct.

Fossils.	Echinodermata.	Temnechinus excavatus.
	Polyzoa.	Fascicularia aurantium.
	Brachiopoda.	Terebratula grandis.
	Lamellibranchiata.	Astarte Omalii.

Red Crag. A ferruginous shelly sand, very false-bedded, resting unconformably on Coralline crag or London clay. Eight per cent. of the mollusca are extinct. There is a phosphate bed at the base.

Fossils.	Gasteropoda.	Voluta Lamberti. Trophon antiquum (Fusus contrarius). Purpurea tetragona.
	Lamellibranchiata.	Petunculus glycimeris.

In the coprolite bed are shark's teeth, and bones of mastodon, Rhinoceros, tapir, etc.

Norwich crag. Shelly sand and gravel, containing a mixture of land, freshwater and marine species with some Arctic forms, foreshadowing the great invasion of Arctic plants and animals into S.Europe, which occurred during the following period. Seven per cent. of the mollusca are extinct.

Fossils.	Lamellibranchiata.	Astarte borealis. Cardium edule. Tellina obliqua.
	Mammalia.	Mastodon arvernensis. Elephas meridionalis. E.antiquus. etc.

Chillesford beds. Sixty-seven per cent. of the shells are Arctic.

Cromer Forest bed. Of uncertain age, but lies beneath the Bure valley beds. It is a land and estuarine deposit of trees, lignite beds and clay, with remains of Elephas meridionalis, E.antiquus, Hippopotamus major, Rhinoceros etruscus, Bison priscus, Beaver, Deer etc.

Bure valley beds possibly form the upper part of the Norwich crag series, but have been considered by some as of Glacial age.

Continental Pliocene. The English beds are quite insignificant compared with the immense thickness of the Italian Pliocene deposits.

The Antwerp crag is considered by some to be a passage bed between Older Pliocene and Upper Miocene.

The Older Pliocene of Italy forms hills flanking the Appenines, and contains a rich sub-tropical flora, with the same assemblage of animals as in England.

The Newer Pliocene includes the lacustrine strata of the Val d'Arno, containing mammals similar to those in Cromer Forest bed; and in Sicily, they form the base of Etna, consisting of marine strata with volcanic tuffs and lavas.

Further eastwards there is evidence of the gradual exclusion of the sea from the area which it covered in Miocene times.

Economic products. The coprolite beds have been worked. The upheaval of the sea floor in Austro-Hungary led to the formation of much rock salt and gypsum, the immense salt works of Wieliczka being of this age.

QUATERNARY OR POST-TERTIARY TIME.

1. *Post-Pliocene or Pleistocene period.*

Upper Glacial.	Purple boulder-clay (Yorkshire) without chalk. , , , , , , with chalk, containing Bridlington drift. Great chalky boulder-clay.
Middle Glacial.	Sands, gravels and brick-earth, with occasional seams of boulder-clay.
Lower Glacial.	Contorted drift. Cromer Till and Lower boulder-clay.

During the formation of the Crags, there is evidence of a gradual refrigeration of climate, which affected both the Old and New World. It reached such a height that the whole of Europe was buried under snow and ice, extending southwards even as far as Saxony. The Alps and Pyrenees were laden with vast snow-fields, from which enormous glaciers descended into the plains, over-riding ranges of minor hills on their way. In Britain all the Highlands were buried in ice which, partly flowing Eastward, joined a vast ice-sheet coming from Scandinavia. Another part pressed to the S. as far as Northumberland, and a third crossed the Firth of Clyde into Cumberland, where it joined another ice-sheet from the Cumbrian range, and overflowed Anglesey to the S.; while another branch reached the E. shores of England. This Cumbrian branch was so large as to overcome the force of the smaller glaciers descending from the mountains of Wales, for the striations of Anglesey point directly towards the mountains of Cumberland. These arctic indications extended as far S. as Middlesex, S.Wales and S.W. Ireland and to the 50th. deg. N. lat. in Central Europe. This was the culmination of the Glacial period. Then followed a considerable depression of the land beneath an arctic sea, in which floated innumerable ice-bergs. Next came a re-elevation, with renewed glacial conditions. Gradually, after intervals of increase and diminution, the ice retired towards the North.

The existing snow-fields and glaciers of the Pyrenees, Switzerland and Norway are remnants of the great ice-sheet of the Glacial period; while the arctic plants of the mountains are relics of the N. vegetation which was universal from Norway to Spain.

Evidence of Glacial action in England.

1. *Erratics.* Large blocks of granite, gneiss, trap, and Carboniferous limestone are scattered over the whole of England N. of the Thames. Boulders of Shap granite of Cumberland are common in Staffordshire, the valley of the Severn and even, across the central watershed, upon the banks of the Humber.

2. *Striated and polished surfaces* are common in N. Wales, the Lake district and in other localities where the underlying rock was sufficiently hard. But in many cases they are no longer visible, either having been covered up with superficial accumulations or effaced by the disintegrating action of the weather.

3. *Roches Moutonnées and Blocs perchés* are common in mountainous districts, e.g. the Pass of Llanberis.

4. *Moraines.* Llyn Idwal (Pass of Nant Francon) is dammed up by a moraine, and moraine matter lies scattered on either side of the Pass of Llanberis. Moraines are also abundant in other parts of Wales and the Lake district.

5. *Boulder-clay and Till.* Till is nothing more than moraine rubbish on a vast scale, covering much of Scotland and parts of Norfolk.

The Boulder-clay is a mass of unstratified clay, containing blocks and ice-scratched stones scattered irregularly through it. The boulder-clays are attributed by some geologists to the action of icebergs, while others look upon them as the *moraine profonde* of the glaciers themselves.

6. *Glacial gravels, or Marine glacial drift,* cover a large part of Britain, rising to heights of more than 2,000 ft. in Wales. At Moel Tryfaen arctic shells occur 1,300 ft. above sea level.

7. Kames (Scotland) and Eskers (Ireland) are long winding ridges of gravel, of which no very satisfactory explanation has yet been given.

Interglacial periods are proved to have existed by the following facts :-

1. Peaty beds and layers of lignite are found interstratified with beds of glacial origin.

2. Conflicting faunas, viz. bones of Lions, Hyœnas, Hippopotami occur mixed in strata of the same age with those of Reindeer, Mammoth, Musk-sheep and Bear. This has been attributed by some to annual changes of summer and winter temperature, but is now generally believed to be owing to warm interglacial periods, and a consequent recesssion of the glaciers, the animals migrating when the conditions changed.

Evidence of submergence during Glacial times.

1. The older Till is often covered by stratified sands and clays, which must have been deposited in water.

2. Marine shells are found on Moel Tryfaen at 1,300 ft., in Cheshire at 1,200 ft.

3. Raised beaches on the coast of Scotland, 100 ft. above sea level.

Proofs that England was joined to the Continent.

1. Such large animals as Elephant, Rhinoceros etc., could not have lived on a group of icy islands, with scanty vegetation.

2. Similarity of flora shows that Britain must have originally formed part of the European continent.

3. Migration must have been possible, as proved by the conflicting faunas.

2. *Recent period.*

Marine.	Raised beaches. Submarine forests. Shingle beaches.
Fluviatile.	Alluvium. Gravel. Brick-earth.
Sub-aerial.	Bone-cave deposits. Soils. Peat-mosses. Blown sand.

The above table is obviously not in chronological order.

Raised beaches are common along the coasts of Devon and Cornwall, Weston-super-mare, and at Portland.

Submarine forests occur along the S.Coast of England.

Shingle beaches, as at the Chesil bank, 15 miles long, from Burton Bradstock to Portland. The pebbles have all come originally from the W. and increase in size eastwards.

Alluvium. The most recent river deposits, forming marshy flats.

Gravels (river) may be divided into *Low-level* or *Valley* gravel, and *High-level* or *Terrace* gravel. The latter was first formed when the stream ran at a higher level.

Brick-earth contains the following fauna:—

Lamellibranchiata.	Cyrena fluminalis, Cyclas cornea, Unio litoralis.
Mammalia.	Elephant, Rhinoceros, Hippopotamus, Hyœna, Bear, Bison, Irish Elk, Cave-lion.

Flint implements occur associated with the bones.

Bone-cave deposits occur at Settle, Kent's hole (Torquay), Brixham, Wokey, Cefn, Kirkdale, Mammoth cave (Kentucky), Somme valley, and Mentone. In England they contain remains of Bear, Wolf, Cave-Hyœna, Cave-Lion, Irish Elk, Bison, Hippopotamus, Wild boar, Rhinoceros, Mammoth, associated with flint weapons.

Soils, *Peat-mosses* and *Blown sand.* See PART I.